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DESCRIPTION

EXPOSURE MASK, METHOD OF DESIGNING AND MANUFACTURING THE SAME, EXPOSURE METHOD AND APPARATUS, PATTERN FORMING METHOD, AND DEVICE MANUFACTURING METHOD

[TECHNICAL FIELD]

This invention relates generally to near field exposure technology that enables production of a fine pattern and, more particularly, to an exposure mask, a method of designing and manufacturing an exposure mask, an exposure method and apparatus, a pattern forming method, and a device manufacturing method, for example.

[BACKGROUND ART]

Increasing capacity of a semiconductor memory and increasing speed and density of a CPU processor have inevitably necessitated further improvements in fineness of microprocessing through optical lithography. Generally, the limit of microprocessing with an optical lithographic apparatus is of an order of the wavelength of light used. Thus, the wavelength of light used in optical lithographic apparatuses haven been

shortened more and more. Currently, near ultraviolet laser is used, and microprocessing of 0.1 µm order is enabled. While the fineness is being improved in the optical lithography, in order to assure microprocessing of 0.1 µm or narrower, there still remain many unsolved problems such as further shortening of laser, development of lenses usable in such wavelength region, and the like.

On the other hand, as a measure for enabling microprocessing of 0.1 µm or narrower, a microprocessing apparatus using a structure of a near-field optical microscope (scanning near-field optical microscope: SNOM), has been proposed. An example is an exposure apparatus in which, by use of evanescent light leaking from a fine opening of a size not greater than 100 nm, local exposure that exceeds the light wavelength limit is performed to a resist.

However, since such lithographic apparatus with an SNOM structure is arranged to execute the microprocessing by use of one or more processing probes, as like continuous drawing. Thus, there is a problem that the throughput is not high.

As one method for solving such problem, U.S. Patent No. 6,171,730 proposes an exposure

method in which a photomask having a pattern arranged so that near field light leaks from a light blocking film, is closely contacted to a photoresist upon a substrate, whereby a fine pattern of the photomask is transferred to the photoresist at once.

The method and apparatus disclosed in the aforementioned U.S. patent is very useful and it makes a large contribution to the technical field to which the present invention pertains.

Also, Japanese Laid-Open Patent Application No. 11-317345 and U.S. Patent No. 6,497,996 disclose that such near field light has a property that the intensity is attenuated as like an exponential function with the distance from the fine opening and, thus, the film thickness of a pattern forming layer based on the near field exposure has to be made thin.

Figure 2 illustrates a near-field electric field distribution around a mask opening obtained by investigation made through simulations. Specifically, Figure 2 shows the state of electric field distribution produced adjacent the opening, where light of a wavelength 436 nm is projected to a near-field exposure mask having a pitch 200 nm and a mask opening width of 70 nm. Values in the drawing are relative electric field intensities at

respective positions where the intensity of incident light is taken as 1.

Seeing the electric field distribution, there is extension from the opening to the light blocking film portion. This means that there is a possibility that the opening pattern of the mask and the pattern provided by exposure do not completely correspond to each other.

The feature that the electric field intensity attenuates as coming away from the mask opening and that there appears an electric field distribution being extended in a direction parallel to the mask surface, such as depicted in Figure 2, is peculiar to the near field.

Generally, making an exposure mask takes a very long time and much cost. In the mask pattern production for near field exposure, particularly the mask design should be done while taking into account this electric field distribution.

On the other hand, as the pattern width to be produced becomes narrower, the mask design should be made while more exactly taking into account the extension described above.

However, if the mask opening width having an electric field distribution that can meet various pattern linewidths and pitches is

sought through complicated simulations using many varieties of parameters, it takes much time to complete the simulation and analysis. Consequently, it causes a problem that the mask designing needs too long time.

[DISCLOSURE OF THE INVENTION]

It is accordingly an object of the present invention to provide an exposure mask, an exposure mask designing and manufacturing method, an exposure method and apparatus, a pattern forming method and/or a device manufacturing method, by which at least one of the inconvenience described above can be solved and by which a mask structure can be accomplished easily while taking into account the electric field distribution peculiar to the near field, without the necessity of complicated simulation that requires a long time.

The present invention can provide an exposure mask, an exposure mask designing and manufacturing method, an exposure method and apparatus, a pattern forming method and a device manufacturing method, which may take the following forms, for example:

(1) An exposure mask for exposing an image forming layer provided on a substrate, by use of

near field light leaking from adjoining openings formed in a light blocking member, characterized in that: the light blocking film has an opening interval that is determined so that an electric field distribution at the image forming layer side of the opening to be defined as exposure light is projected on the light blocking member has a correlation with an eccentric model of electric field distribution as determined by a linewidth and a height of a pattern to be produced.

(2) An exposure mask for exposing an image forming layer provided on a substrate, by use of near field light leaking from adjoining openings formed in a light blocking member, characterized in that: a relation $K \geq (W+2T)$ is satisfied where T is the height of a pattern to be produced by use of the image forming layer, W is the linewidth of the pattern, and K is the width of the light blocking member being present between adjacent openings.

(3) An exposure mask for exposing an image forming layer provided on a substrate, by use of near field light leaking from adjoining openings formed in a light blocking member, characterized in that: a relation $D \leq (P-W-2T)$ is satisfied where T is the height of a pattern to be produced by use of the image forming layer, W is the linewidth of

the pattern, P is the pitch of the pattern, and D is the width of the opening.

(4) An exposure mask for exposing an image forming layer provided on a substrate, by use of near field light leaking from adjoining openings formed in a light blocking member, characterized in that: a relation $D=\{P-W-2T(1+\alpha)\}$ is substantially satisfied where T is the height of a pattern to be produced by use of the image forming layer, W is the linewidth of the pattern, P is the pitch of the pattern, and D is the width of the opening while taking into account a process margin α after the exposure.

(5) An exposure mask as recited in item (3) or (4) above, wherein the value of the pitch is made not grater than the wavelength of a surface plasmon polariton wave to be produced on the basis of the light blocking member.

(6) An exposure mask as recited in any one of items (1) to (5), wherein the openings of the mask have a two-dimensional shape or they are arranged two-dimensionally, with respect to a direction along the surface of the light blocking member where the openings are formed.

(7) A method of designing an exposure mask for exposing an image forming layer provided on a substrate, by use of near field light leaking from

adjoining openings formed in a light blocking member, characterized in that: an opening interval of the light blocking film is determined on the basis of a linewidth and a height of a pattern to be produced by use of the image forming layer.

(8) A method of manufacturing an exposure mask for exposing an image forming layer provided on a substrate, by use of near field light leaking from adjoining openings formed in a light blocking member, characterized in that: an opening interval of the light blocking film is determined on the basis of a linewidth and a height of a pattern to be produced by use of the image forming layer, and that, the light blocking member is subsequently processed so as to obtain the thus determined opening interval.

(9) An exposure method for exposing an image forming layer provided on a substrate, by use of an exposure mask having a light blocking member with an opening and on the basis of near field light leaking from the opening, characterized by: a step of preparing an exposure mask as recited in any one of items (1) to (6); a step of approximating the near-field exposure mask and the image forming layer to each other, up to a distance not greater than a near field region; and an exposure step for irradiating the image forming

layer with exposure light through the exposure mask.

(10) An exposure method as recited in item (9), wherein, where P is the pitch of a pattern to be produced by use of the image forming layer, D is the width of the opening, W′ is the linewidth, and T′ is the pattern height, through adjustment of an exposure amount in the exposure step and of another condition or conditions, an exposure is carried out to satisfy a relation $(W'+2T') \leq (P-D)$.

(11) A pattern forming method including an exposure step for exposing an image forming layer on the basis of near field light and by use of a near-field exposure mask having a light blocking member with openings having a pitch P and an opening width D, and a developing step for developing the exposed image forming layer, characterized in that: through adjustment of an exposure amount in the exposure step and a developing condition in the developing step, a pattern having a linewidth W and a height T satisfying a relation $(W+2T) \leq (P-D)$ is produced.

(12) A method as recited in item (11), wherein, where a minimum value of the height T of the pattern is determined as T″ due to process after the pattern formation, a pattern having a linewidth W that satisfies a relation $W \leq (P-D-2T'')$

is produced.

(13) A device manufacturing method characterized by including an exposure step for exposing a process object by use of an exposure method as recited in item (9), and a developing step for developing the exposed process object, wherein, after these steps, a predetermined process is conducted to the process object, whereby a device is manufactured.

(14) An exposure apparatus including light irradiating means and an exposure mask, for exposing a process object provided on a substrate, by use of near field light leaking from a plurality of openings formed in a light blocking member of the mask, characterized in that: as the exposure mask, said exposure apparatus comprises an exposure mask as recited in any one of items (1) to (6).

In accordance with the present invention, it is possible to accomplish an exposure mask, an exposure mask designing and manufacturing method, an exposure method and apparatus, a pattern forming method and/or a device manufacturing method, by which a mask structure can be accomplished easily while taking into account the electric field distribution peculiar to the near field, without the necessity

of complicated simulation that requires a long time. Therefore, design and production of a near-field exposure mask can be achieved efficiently. Particularly, in the production of a desired fine pattern not greater than the wavelength of light used for the exposure, the throughput can be improved significantly and, thud, the cost can be decreased well.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Figure 1 is a schematic view for explaining the present invention and, specifically, it illustrates how to determine an opening width of a near-field exposure mask on the basis of a concentric-circle model.

Figure 2 is a schematic view for explaining the present invention and, specifically, it illustrates a simulation result that shows an electric field intensity produced adjacent the openings.

Figure 3 is a schematic view for

explaining the present invention and, specifically, it illustrates a simulation result that shows an electric field intensity produced adjacent the openings, as well as a concentric-circle model.

Figure 4 is a schematic view for explaining how to determine an opening width of a near-field exposure mask on the basis of a concentric-circle model, in accordance with an embodiment of the present invention.

Figure 5 is a schematic view of a general structure of a near-field exposure mask according to an embodiment of the present invention.

Figure 6 is a sectional view showing a general structure of a near-field exposure apparatus according to an embodiment of the present invention.

Figure 7 is a graph illustrating a solubility curve of a certain resist.

Figure 8 is a schematic view for explaining a pattern width W′ produced through near field exposure in accordance with an embodiment of the present invention.

Figures 9A - 9C′ illustrate examples of resist patterns which are obtainable from masks having a two-dimensional shape pattern, wherein Figures 9A and 89′ are a case where a mask pattern

having a grid-like fine openings is used, wherein Figures 9B and 9B′ are a case where a mask having a two-dimensional fine opening array is used, and wherein Figures 9C and 9C′ are a case wherein a mask whose light blocking metal film has a two-dimensional rectangular array is used.

Figures 10A and 10B illustrate a resist pattern obtainable when a mask having a two-dimensional shape pattern is used, and specifically, Figure 10A shows a resist pattern obtainable where a mask that has a light blocking metal film having a ring-like shaped is used.

Figure 11 is a schematic view for explaining the present invention and, specifically, it illustrates how to determine a minimum value of opening interval of a near-field exposure mask in accordance with a concentric-circle model.

[BEST MODE FOR PRACTICING THE INVENTION]

In accordance with the present invention, it is enabled to provide an exposure mask, an exposure mask designing and manufacturing method, an exposure method and apparatus, a pattern forming method and/or a device manufacturing method, by which a mask structure can be accomplished easily while taking into account the electric field distribution peculiar

to the near field, without the necessity of complicated simulation that requires a long time. This is based on the following findings acquired by the inventors of the present invention.

Namely, in the mask designing taking into account the extension peculiar to the near field, from simulations it has been found that the electric field distribution adjacent the opening of a mask from which near field light emits takes the form of an electric field distribution having an approximately concentric extension. Also, it has been found that such electric field distribution can be approximated by a concentric-circle model, and that, by using such concentric-circle model and from the pattern width W and pattern height T (pitch P in the case of a periodic pattern), the structure of a near-field exposure mask to be prepared can be determined easily by equations, without the necessity of simulations.

This will be explained in greater detail.

Figure 2 shows a near-field electric field distribution produced near fine openings. This is the result of simulation made by use of a kind of GMT (Generalized Multipole Technique) program, that is, "Max-1" (C.IIafner, Max-1, A

Visual Electromagnetics Platform, Wiley, Chichester, UK, 1998). GMT is one analysis method of Maxwell equation, wherein a scattered wave is described while a multipole is placed as a virtual source. As regards a mask base material 102, SiN was used and, regarding a light blocking film 101, Cr was used. The pitch of the fine opening pattern was 200 nm, and the opening width was 70 nm. The incident wavelength was 436 nm.

Numerical values (0.2, 0.4, 0.6, ... 1.0, 1.2, and so on) in the drawing are a relative electric field intensity where the electric field intensity of the incident light is taken as 1.0.

Figure 2 in fact illustrates an electric field distribution peculiar to the near field, wherein the intensity decreases as like an exponential function, as becoming away from the fine opening. Analyzing this distribution in greater detail, it has been found that the electric field intensity takes a peak value at an edge portion, at the light blocking film, of the fine opening and, from there, the intensity attenuates as like expanding as a concentric circle. Also, it has been found that, even with a different opening width or opening interval or a different pitch pattern, simulation of electric field distribution to the near-field mask shows

similar results, particularly when, for a periodic pattern, the pitch of the fine opening pattern is not greater than the surface plasmon polariton wave and the light blocking film is made of a different material, that is, Au or Ta.

In the present invention, the term "opening width" refers to the width of an opening defined by forming a light blocking film, constituting a mask, where no light blocking film is present there. Specifically, in Figure 1, for example, the portion denoted at Dmax corresponds to it. Also, the term "opening interval" refers to the distance between two adjacent openings, that is, the width of the light blocking film there. Specifically, in Figure 11, for example, the portion denoted at Kmin corresponds to it.

Modeling such distribution, Figure 3 illustrates a combined result of a modeled near-field distribution (right-hand side of Figure 3) and the simulation results of Figure 2 (left-hand side of Figure 3). In Figure 3, for simplicity of illustration, a portion of the field contour line shown in Figure 2 is omitted.

It is seen from Figure 3 that, through a concentric-circle model 600, distribution adjacent the light blocking film edge portion and distribution from the edge portion to a portion

601, below the light blocking film, are quite well approximated. Namely, the concentric-circle model 600 well depicts the feature that the extension distance in the film-thickness direction (downward direction in Figure 3) in the simulation result and the extension distance in a direction parallel to the mask surface (horizontal direction as viewed in Figure 3) are similar to each other.

To the contrary, in this model, except the light blocking film edge portion and the portion from the edge portion to the portion below the light blocking film, that is, at a portion below the opening (as long as a produced pattern of exposure concerns), the electric field distribution is not approximated well. Particularly, as the opening width becomes wider, the electric field intensity distribution deviates off the model. Since, however, from the simulation result, there is a tendency that the electric field intensity below the opening increases as the opening width becomes wider, it can be considered that the portion below the opening is exposed constantly. Actually, in practical experiments, a result corresponding to the simulation result was obtained at the portion blow the opening.

By using this model, the structure of a

near-field exposure mask to be prepared in order to obtain a desired pattern can be determined without the necessity of complicated and massive simulations using various parameters and analysis of the results. This will be described in detail, below.

Once the type of the image forming layer is fixed, the pattern to be produced in the image forming layer can be determined by exposure amount and developing condition. Thus, where an electric field distribution having a concentric extension as of the above-described model is produced, the pattern width thereof can have a freedom if the exposure amount and developing condition are chosen appropriately.

First of all, a case where a desired pattern to be produced is a periodic pattern will be explained. For a periodic pattern having a pitch P, also the pitch of the mask fine opening pattern should be equal to P. For production of one having a pattern width W, from the concentric-circle model described above, a relation of the following equation (1) should be satisfied between the maximum value Dmax of the mask opening width and the film thickness T of the image forming layer:

$$Dmax = P-W-2xT \quad \ldots(1)$$

If the relation is described with respect to D as the mask opening width is not limited to a maximum value, it can be set forth as follows:

$$D \leq P-W-2T$$

Here, T is the pattern height of the image forming layer 401 as determined by a subsequent process or processes.

Figure 1 shows the relationship of values in equation (1). Thus, referring to the drawing, equation (1) will be explained in greater detail. First, the pattern height T of the image forming layer 401 by which a desired processing depth of a process object substrate 402 can be processed, is determined on the basis of a process condition such as etching durability, for example. In order to make a pattern of this height T, it is necessary that a pattern after development is produced at the field contour line portion outside the field contour line 800, depicted by a thick line in Figure 1.

The electric field distribution below the light blocking film 101 is well approximated by a concentric-circle model 600, as described hereinbefore. It is seen from Figure 1 that the extension from the edge portion of the light blocking film 1 is approximately even both in

regard to the film thickness direction (downward direction as viewed in Figure 1) and in a direction parallel to the mask surface (horizontal direction as viewed in Figure 1). Therefore, if a pattern after development is produced at the electric field contour line 800 or any electric field contour line outside the line 800, it assures a result that a developed pattern having an extension not less than a distance T, from the edge portion of the light blocking film 101, even in the direction parallel to the mask surface, is produced.

The extension phenomenon from the edge portion of the light blocking film 101 similarly occurs at the opposite side edge of the light blocking film 101.

Thus, the largest opening width Dmax of the near-field exposure mask, effective to produce a pattern having a pattern width W just underneath the light blocking film 101, can be set as defined in equation (1), by using the pattern pitch P, width W and height T.

As regards the image forming layer, any material may be used provided that reaction occurs in response to the near field from the opening and it can bear a process after the pattern formation. As regards the versatility, however, use of

photoresist is preferable.

The value T may be determined by a process or processes after the pattern formation and, more specifically, the etching durability in the etching process for the process object substrate, or the film thickness of vapor deposition in the lift-off, for example.

Although it is desirable that a pattern of a thickness having a durability to the processing for the process object substrate can be produced only by the image forming layer, if a thickness not less than (P-W)/2 is necessary, a buffer layer may be prepared between the image forming layer 401 and the process object substrate.

The buffer layer may be a resist layer, an oxide film layer, or a metal layer, for example, not processed or, alternatively, processed so as to provide a physical property different from the image forming layer, such as, for example, hard baking or non-silylating in a case where a surface imaging method (e.g. multilayer resist method or surface layer silylating method), for example, is used. The buffer layer may be a single layer or it may comprise plural layers. By transferring a pattern, having been formed in the image forming layer 401 on the basis of near field exposure, to such buffer layer in accordance with a method such

as dry etching method, for example, one having a thickness sufficiently durable to the processing to be made to the process object substrate can be produced.

The value by which the opening width D becomes equal to Dmax is the value by which the process margin becomes equal to zero. In this specification, the term "process margin" refers to a factor that defines the tolerance of process with which a desired pattern height T and a desired pattern linewidth can be assuredly obtainable even taking into account a process to be performed after the exposure.

The process margin "zero" means that the margin for the process condition such as exposure developing condition for the pattern formation or the process after the pattern formation, such as etching or vapor deposition, is zero. With such "zero" margin, actually it is very difficult to perform the pattern formation and subsequent processes for the process object substrate.

Therefore, while taking into account the process margin, the value of the opening width D should desirably be made smaller than Dmax, as given by equation (2) below:

$$D = P-W-2T(1+\alpha) \qquad \ldots(2)$$

wherein α is the process margin. More specifically, it may be a component of overall film thickness dissolution during the development of image forming layer, or a component of dissolution in a direction parallel to the substrate surface during the development of the image forming layer, for example.

While the valueα varies largely with the process, in many cases it takes a value of $0<\alpha\leq4$. If equation (2) takes a negative value in dependence upon the value of α, a buffer layer may be provided between the image forming layer and the process object substrate as described hereinbefore, to reduce the values of α and T of the effective image forming layer, such that the opening width D having an effective and positive value can be set.

Figure 4 shows the relationships of these values. The reference "αp" in Figure 4 is a value as determined by a relation $0\leq\alpha p\leq\alpha$. While α is defined as the process margin, not only it includes the margin with respect to the film thickness direction but also it embraces the margin with respect to a direction along the mask surface. Thus, the component αp of margin α only in the film thickness direction is added to the pattern height T.

A near-field exposure mask having an opening pattern pitch P and an opening width D, having been designed in the manner described above, is manufactured, and near-field exposure and development are carried out by use of the mask, by which a fine pattern can be produced. Details will be described below.

Figure 5 illustrates a general structure of a near-field exposure mask according to an embodiment of the present invention. The near-field exposure mask 1 comprises a light blocking film 101, a mask base material 102 and a mask supporting member 103. A thin film portion 104 that presents an effectual near-field exposure mask, contributable to exposure, is defined by supporting the mask base material 102 through the mask supporting member 103. The light blocking film 101 may comprise a material having a low transmissivity to exposure light to be described later, such as Cr, Al, Au or Ta, for example.

The mask base material 102 may comprise a material having a transmissivity to exposure light to be described later, such as SiN, SiO_2, or SiC, for example, having a property different from the light blocking film 101. There are fine openings 105 formed in the light blocking film 101, the openings having a shape like a slit or bore.

These openings are formed in the thin film portion 104 constituted by the light blocking film 101 and the mask base material 102 only. As will be described later, these openings are provided so as to produce near field light (evanescent light) at a front surface of the mask in response to irradiation of the mask exposure light from the rear surface of the mask (upper surface thereof in Figure 1).

The pitch and opening width of the fine opening pattern of the near-field exposure mask are made to be equal to P and D having been designed as described hereinbefore.

The opening pattern may be formed by use of a processing machine such as FIB, EB, X-ray or SPM, or in accordance with a nano-imprint method or a fine pattern forming method based on near field exposure.

Next, referring to Figure 6, a method of producing a fine pattern by use of an exposure apparatus 2, which is an example for performing exposure with use of an exposure mask 1 as has been described above, will be explained.

Figure 6 is a sectional view showing a general structure of an exposure apparatus 2 according to an embodiment of the present invention. As shown in Figure 2, the exposure

apparatus 2 comprises a light source unit 200, a collimator lens 300, an exposure mask 100, an exposure object 400 to be exposed, and a pressure adjusting system 500.

Regarding major components of the exposure apparatus 2, the exposure apparatus 2 is arranged so that, by using the exposure mask 100 that corresponds to the whole surface of the exposure object 400, a predetermined pattern formed on the exposure mask 100 is transferred to the exposure object 400 at once.

The present embodiment can be accomplished with various exposure methods such as, for example, a step-and-repeat exposure method wherein an exposure mask 100 smaller than an exposure object 100 is used and wherein exposure of a portion of the exposure object is carried out repeatedly while changing the position of the exposure subject 400, or a step-and-scan exposure method.

Here, the term "step-and-scan exposure method" refers to such projection exposure method that: an exposure mask 100 corresponding to one shot (one shot region covers one or more chip regions) is disposed opposed to one shot region of an exposure object 400, and the exposure mask 100 and the exposure object 400 are relatively and

continuously scanned by exposure light, whereby a pattern of the exposure mask 100 is lithographically transferred onto the exposure object; while on the other hand, after completion of exposure of one shot, the exposure object 400 is moved stepwise so that a subsequent shot region of the exposure object 400 is disposed opposed to the exposure mask 100, and then the scanning exposure process described above is repeated.

Also, the term "step-and-repeat exposure method" refers to such projection exposure method that: each time simultaneous exposure of one shot of an exposure object 400 is completed, the exposure object 400 is moved stepwise to move the same to the exposure region of a subsequent shot (i.e. the position to be opposed to the exposure mask 100), and then the simultaneous exposure is repeated.

In this embodiment, where the step-and-scan exposure method or step-and-repeat exposure method is to be carried out, for every stepwise motion, separation operation of the mask from the exposure object 400 should be done before the stepwise motion and also intimate-contacting operation of the mask to the exposure object 400 should be done after the stepwise motion.

The light source unit 200 has a

function for producing illumination light for illuminating the exposure mask 100 having formed thereon a transfer circuit pattern to be transferred to the substrate. As an example, it may comprise an Hg lamp as a light source that can emit ultraviolet light. However, the lamp is not limited to the Hg lamp, but xenon lamp or deuterium lamp, for example, may be used. Also, there is no restriction in regard to the number of light sources.

Further, the light source to be used in the light source unit 100 is not limited to lamp, but one or more lasers may be used. For example, a laser that can emit ultraviolet light or soft X-rays may be used. ArF excimer laser having a wavelength of about 193 nm, KrF excimer laser having a wavelength of about 248 nm, or F2 excimer laser having a wavelength of about 153 nm, for example, may be used. The type of laser is not limited to excimer laser, and YAG laser, for example, may be used. There is no restriction in regard to the number of lasers.

The collimator lens 300 functions to transform the illumination light emitted from the light source unit 200 into parallel light which in turn is introduced into a pressuring vessel 510 of the pressure adjusting system 500, whereby the

whole surface of the exposure mask 100 or only a portion thereof which is going to be exposed is illuminated with uniform light intensity.

As has been described with reference to Figure 5, the exposure mask 100 comprises a light blocking film 101, a mask base material 102, and a mask supporting member 103. From the light blocking film 101 and the mask base material 102, a thin film 104 being elastically deformable is provided. The exposure mask 100 is arranged so that a pattern as defined by the fine opening pattern 105 of the thin film 104 is transferred to the image forming layer 401 at a unit magnification, on the basis of near field light. Here, the term "unit magnification" does not mean exact "1x" magnification, but it is mentioned to emphasize that the magnification differs from that in the transfer by reduction projection.

Regarding the exposure mask 100, the lower surface thereof as viewed in Figure 6 is the front surface of the mask as being mounted. The light blocking film 101 is disposed outside the pressuring vessel 510 of the pressure adjusting system 500. The thin film 104 can be elastically deformed to assure close contact with any surface irregularities of the image forming layer 401 or with any waviness of the exposure object 400.

The exposure object 400 comprises a process object substrate such as a wafer, for example, and an image forming layer 401 applied thereto. The exposure object 400 is mounted on a stage 450.

As regards the image forming layer 401, use of a photoresist to be used in ordinary photolithography is preferable. As regards the resist material, use of one having a large contrast value is preferable. The film thickness of the resist is T, as described hereinbefore. The application procedure for the image forming layer 401 includes a pre-process, a resist coating process and a pre-baking process.

The process object substrate can be chosen from a wide variety of materials such as semiconductor substrate (e.g. Si, GaAs or InP), insulative substrate (e.g. glass, quartz or BN), or one provided by such substrate material and having a film of metal, oxide or nitride, for example, formed thereon. However, it should be intimately contacted to the exposure mask 100 throughout the whole exposure region with a clearance of preferably not greater than 10 nm, and at least not greater than 100 nm. Therefore, for the substrate 402, one having a good flatness as much as possible should be chosen.

During the exposure, the image forming layer 401 and the exposure mask 100 should be close to each other for execution of exposure based on the near field light, and they are relatively approximated to each other up to a clearance of about 100 nm or less.

The stage 450 is driven by an external equipment, not shown. It functions to align the exposure object 400 relatively and two-dimensionally with respect to the exposure mask 100, and also it operates to move the exposure object 400 upwardly and downwardly as viewed in Figure 3.

The stage 450 of this embodiment has a function for moving the exposure object 400 between a loading/unloading position (not shown) and the exposure position shown in Figure 3. At the loading/unloading position, a fresh exposure object 400 not having been exposed is loaded on the stage 450 while, on the other hand, an exposure object 400 having been exposed is unloaded therefrom.

The pressure adjusting system 500 serves to facilitate good intimate contact and separation between the exposure mask 100 and the exposure object 400, more particularly, between the thin film portion 104 and the image forming

layer 401. If both of the surfaces of the exposure mask 100 and the image forming layer 401 are completely flat, they can be brought into intimate contact with each other throughout the entire surface, by engaging them with each other. Actually, however, the surfaces of the exposure mask 100, the image forming layer 401 and substrate 402 have a surface irregularity or surface waviness. Therefore, only by approximating them toward each other and bringing them into engagement with each other, the result would be mixed distribution of intimate contact portions and non-intimate contact portions. In the non-intimate contact portion, the exposure mask 100 and the exposure object 400 are not held within a range of distance through which the near field light effectively functions. Therefore, it would result in exposure unevenness.

In consideration of it, the exposure apparatus 2 of this embodiment is provided with a pressure adjusting system 500 which comprises a pressurizing vessel 510, a light transmission window 520 made of a glass material, for example, pressure adjusting means 530, and a pressure adjusting valve 540.

The pressurizing vessel 510 can keep the gas-tightness through the combination of the

light transmission window 520, the exposure mask 100 and the pressure adjusting valve 5540. The pressurizing vessel 510 is connected to the pressure adjusting means 430 through the pressure adjusting valve 5540, such that the pressure inside the pressurizing vessel 510 can be adjusted. The pressure adjusting means 530 may comprise a high-pressure gas pump, for example, and it functions to increase the inside pressure of the pressurizing vessel 510 through the pressure adjusting valve 540.

The pressure adjusting means 530 further comprises an exhausting pump (not shown), so that it can function to decrease the inside pressure of the pressurizing vessel 510 through a pressure adjusting valve, not shown.

The adhesion between the thin film and the image forming layer 401 can be adjusted by adjusting the inside pressure of the pressurizing vessel 510. If the surface of the exposure mask 100, the image forming layer 401 or of the substrate 402 has slightly large surface irregularities or waviness, the inside pressure of the pressurizing vessel 510 may be set at a higher level to increase the adhesion strength, thereby to reduce dispersion of clearance between the surfaces of the mask surface 100, the image

forming layer 401 and the substrate 402 due to the surface irregularities or waviness.

As an alternative, the front surface side of the exposure mask 100 as well as the image forming layer 401 and the substrate 402 side may be disposed inside a reduced-pressure vessel 510. In that occasion, on the basis of a pressure difference with an atmospheric pressure, higher than the vessel inside pressure, a pressure may be applied to the exposure mask from its rear surface side to its front surface side, whereby the adhesion between the exposure mask 100 and the image forming layer 401 can be improved. Anyway, a pressure difference that the pressure at the rear surface side of the exposure mask 100 is higher than the pressure at the front surface side thereof, is produced. If the surface of exposure mask 100 or the surface of image forming layer 401 or substrate 401 has slightly large surface irregularities or waviness, the pressure inside the reduced pressure vessel may be set at a lower level to increase the adhesion, thereby to reduce dispersion of clearance between the mask surface and the resist surface or substrate surface.

As a further alternative, the inside of the pressurizing vessel 510 may be filled with a liquid which is transparent with respect to the

exposure light EL and, by using a cylinder (not shown), the pressure of the liquid inside the pressurizing vessel 510 may be adjusted.

Next, the sequence of exposure using the exposure apparatus 2 will be explained.

For exposure, the stage 450 aligns the exposure object 400 with respect to the exposure mask 100 relatively and two-dimensionally.

If the alignment is completed, the stage 450 moves the exposure object 400 along a direction of a normal to the mask surface, into a range that, throughout the entire surface of the image forming layer 401, the clearance between the image forming layer 401 and the exposure mask 100 is reduced to not greater than 100 nm so that they can be intimately contacted to each other on the basis of elastic deformation of the thin film 104.

Subsequently, the exposure mask 100 and the exposure object 400 are brought into intimate contact with each other. Specifically, the pressure adjusting valve 540 is opened and the pressure adjusting means 530 introduces a high pressure gas into the pressurizing vessel 510, whereby the inside pressure of the pressurizing vessel 510 is raised. After this, the pressure adjusting valve 540 is closed.

As the inside pressure of the

pressurizing vessel 501 increases, the thin film 104 is elastically deformed and it is pressed against the image forming layer 401.

As a result, the thin film 104 is closely contacted to the image forming layer 401 with uniform pressure, throughout the entire surface and within a range in which the near field light effectively acts on the image forming layer. Where pressure application is performed in the manner described above, in accordance with the Pascal's principle the repulsive force acting on between the thin film 104 and the image forming layer 401 becomes uniform. This effectively avoids a phenomenon that a large force is locally applied to the thin film 104 or the image forming layer 401, and thus it effectively prevents local breakage of the exposure mask 100 or the exposure object 400.

In this state, the exposure process is carried out. Namely, exposure light is emitted from the light source unit 200 and it is transformed into parallel light by means of the collimator lens 300. Then, the exposure light is introduced into the pressuring vessel 510 through the glass window 520. The thus introduced light passes through the exposure mask 100, disposed inside the pressurizing vessel 510 from its rear

surface side to its front surface side, that is, from the upper side to the lower side in Figure 3, whereby near field light leaking from the pattern defined by the fine openings of the thin film 104 is produced.

The near field light is scattered within the image forming layer 401, such that the image forming layer is exposed thereby. Where the thickness of the image forming layer 401 is sufficiently thin, the scatter of near field light within the image forming layer 401 does not expand largely, such that a pattern corresponding to the fine opening, smaller than the wavelength of exposure light, can be transferred to the image forming layer 401.

After the exposure is completed, a valve (not shown) is opened and the inside of the pressurizing vessel 510 is evacuated through an exhaust pump (not shown) of the pressure adjusting means 530, thereby to decrease the pressure of the pressurizing vessel 510. Then, the thin film 104 is separated (or peeled) off from the image forming layer 401 on the basis of elastic deformation.

Where pressure reduction is performed in the manner described above, in accordance with the Pascal's principle the repulsive force acting

on between the thin film 104 and the image forming layer 401 becomes uniform. This effectively avoids a phenomenon that a large force is locally applied to the thin film 104 or the image forming layer 401, and thus it effectively prevents local breakage of the exposure mask 100 or the exposure object 400.

After this, the exposure object 400 is moved by the stage to the loading/unloading position where it is replaced by a fresh exposure object 400. Subsequently, a similar procedure is repeated.

Here, the exposure amount can be set in the following manner.

The electric field distribution where a near field exposure mask prepared as described above can be determined on the basis of simulation. Furthermore, if the relationship of the remaining film thickness after development with respect to the exposure amount of the used image forming layer, namely, the solubility curve of the resist, is predetected, on the basis of it, the exposure amount and the developing condition are determined so that a desired pitch P and a desired pattern width W are obtained.

More specifically, first of all, from the simulation result, the electric field contour

line where a desired pattern width is obtainable when the intensity of incident light upon the near-field exposure mask is taken as 1, is read out. This is denoted by "x". Also, from the resist solubility curve, the exposure amount with which the standardized remaining film thickness becomes equal to 0.5 is read out. This is denoted by "I".

As an example, Figure 7 shows a solubility curve of a representative resist. If a used resist is a negative resist, the above value takes the same value of the sensitivity. If it is a positive resist, the above value takes a value as designated in Figure 7 by an inclined arrow.

If the intensity of incident light on the near-field exposure mask is J, then J and t that satisfy the relation:

$$I = xJt \qquad \ldots(3)$$

are set as the intensity of incident light and the exposure time, respectively. Namely, Jt is set as the exposure amount.

As an example, a case will be explained in more detail with reference to Figure 4.

First, an electric field contour line 800 with which a desired pattern width is obtainable is chosen. Regarding the contour line 800, from the simulation result, the intensity

thereof was 0.5 where the incident intensity was taken as 1. Also, from the solubility curve of a used resist, the exposure amount with which the standardized remaining film thickness became equal to 0.5 was 220 mJ/cm^2. Where light of 200 mW/cm^2 is used as the incident intensity, if follows from equation (3) that:

$$220 = 0.5 \times 200 \times t$$

such that an exposure time 1.2 sec. and an exposure amount 240 mJ/cm^2 are calculated.

It is sufficient that the simulation is done only in regard to a near-field exposure mask having already determined pitch and opening width, that is, only with regard to one condition. Further, the number of parameters required for conditioning the process is much reduced. Therefore, the time from a desired pattern is given to completion of actual manufacture, is reduced considerably.

On the other hand, in regard to a near-field mask having already determined pitch and opening width, without simulation the exposure amount and developing condition with which a desired pattern width W is obtainable can be determined on the basis of a formed pattern produced when the exposure amount and developing condition are changed. Since there is no

necessity of repeatedly performing complicated simulations with various parameters, in the design of near field exposure mask, the time required for the mask designing is reduced remarkably.

By developing the resist having a latent image formed therein in the manner described above, a fine resist pattern of a desired size can be produced. Thereafter, an appropriate process to the substrate such as dry etching, wet etching, or lift-off, for example, or transfer to a background resist layer, may be carried out.

A specific example of the present invention will be explained, while specifying its numerical values.

As an example, a periodic slit structure having a pitch 200 nm and a pattern width 20 nm is going to be produced upon an SIO (silicon-on-insulator) wafer having an SIO layer of 100 nm thickness. Applying this to the aforementioned symbols, it follows that P = 200 nm and W = 20 nm.

In order that the process object substrate is an SIO layer, i.e. Si layer, and that the Si layer is etched through a depth 100 nm, taking into account the margin of dry etching, the resist layer as the mask layer should have a

thickness of not less than 100 nm. Thus, it follows that:

$$T(1+\alpha) = 100 \text{ nm}$$

Applying this to equation (2), the left-hand term becomes negative and, thus, a buffer layer is provided between the image forming layer and the process object substrate. More specifically, a dual-layer resist method is used. A hard-baked resist layer is formed as a buffer layer upon the process object substrate, with a thickness 100 nm. On this layer, a Si-containing resist is formed as an image forming layer, with a thickness 20 nm. The thickness is set so that the image forming layer functions as an etching mask when the image forming layer pattern is transferred to the hard-baked layer. Specifically, T = 20 nm.

Regarding the process margin, when $\alpha = 1.5$ is chosen from its range "$0 \leq \alpha \leq 4$", from equation (2) the mask opening width D [nm] can be given by:

$$D = 200-20-2\text{x}20\text{x}(1+1.5) = 80$$

In consideration of this, a mask having a pitch 200 nm and an opening width 80 nm was made as a near field exposure mask.

Using this mask, a buffer layer and an image forming layer set as has been described

above were produced on the Si layer. Through exposure and development, a pattern having a pitch 200 nm was produced in the image forming layer. Using this as an etching mask, an etching process was carried out with a dry etching apparatus and an oxygen gas, a slit pattern having a pitch 200 nm and a pattern width 20 nm was produced on the buffer layer.

Further, using the pattern of the buffer layer as an etching mask, Si was etched with a dry etching apparatus, whereby a fine Si structure having a pitch 200 nm, a pattern width 20 nm and a pattern height 100 nm was produced upon an insulative film.

By the way, where a mask having any one of a variety of two-dimensionally shaped mask patterns 801 such as shown in Figures 9 and 10 is applied to a near-field exposure mask of the present invention such as described hereinbefore, just underneath the mask a latent image of two-dimensional shape such as illustrated at 803 is produced. After exposure and development, a resist pattern 802 corresponding to it is produced.

For example, with a mask pattern having grid-like fine openings (Figure 9A), a two-dimensional dot array (in the case of positive type resist) such as shown in Figure 9A′ or a hole

array (in the case of negative type resist) is obtainable. These patterns may be suited for production of a two-dimensionally arrayed quantum dot array to be used for an optical device or electronic device having quantum dots.

On the other hand, with a mask pattern having a two-dimensional fine-opening array such as shown in Figure 9B, a two-dimensional grid-like array (in the case of positive type resist) such as shown in Figure 9B′ or a hole array (in the case of negative type resist) is obtainable.

In the case of a mask pattern wherein a light blocking metal film portion has a two-dimensional rectangular array such as shown in Figure 9C, a two-dimensional fine-line pair (in the case of positive type resist) such as shown in Figure 9B′ or a fine groove array (in the case of negative type resist) is obtainable. These patterns may be suited for production of a gate pattern to be used in a CMOS electronic device.

Further, in the case of a mask pattern wherein a light blocking metal film portion has a ring-like shape, such as shown in Figure 10A, a two-dimensional dot or ring array (in the case of positive type resist) such as shown in Figure 10B or a hole or ring array (in the case of negative type resist) is obtainable.

The foregoing description has been made with reference to a method of producing a pattern having a desired pitch P, a desired pattern width W and a desired pattern height T by use of a near field exposure mask having an opening width D designed and manufactured as described hereinbefore. However, on the basis of a method such as adjusting the exposure amount, changing the used resist, changing the developing condition or the like, a pattern having either one or both of a pattern width W′ and a pattern height T′ different from W and T and satisfying the following relation, may be manufactured:

$$(W'+2T') \leq (P-D) \quad \ldots(4)$$

As an example, the exposure amount may be increased as compared with the method having been described hereinbefore, or the sensitivity of a used resist may be increased, or the developing time may be increased. Any one of them or two of them may be performed and, in that occasion, a pattern having a pattern width W′ satisfying a relation $W'<W$, even for the same pattern height, i.e. $T=T'$, is obtainable.

Furthermore, a pattern having a pattern width W′ satisfying a relation $W'>W$ is obtainable when any one or two of (i) choosing the image forming layer height satisfying $T'<T$ and

developing the exposure amount, (ii) decreasing the resist sensitivity, and (iii) shortening the developing time.

An example will be explained in detail, with reference to Figure 8. Where a desired pattern height T′ is equal to T, an electric field contour line 801 (depicted by a thick line in Figure 8) which is outside the electric field contour line 800 (depicted by a thick line in Figure 1), is chosen. Subsequently, the above-described exposure amount and developing condition are set to assure that a pattern can be produced with the field contour line 801. If a used material of the image forming layer 401 is the same, by increasing the exposure amount, for example, a pattern having a pattern width W′ different from W and satisfying a relation W′<W can be produced from an already prepared mask having a pitch P and an opening width Dmax. Here, the values of W′ and T′(=T) satisfy equation (4).

Subsequently, a case where a desired pattern to be produces is an isolated pattern, will be explained. In order to produce a pattern having a pattern width W, from the concentric-circle model described hereinbefore, a relation (5) below should be satisfied between a minimum value Kmin of the mask opening interval and the

film thickness T of the image forming layer.

$$Kmin = W+2T \quad \ldots(5)$$

Describing it as K where the mask opening interval is not limited to a minimum value, it follows that:

$$K \geq W+2T$$

Figure 11 shows the relationship of the values in equation (5). Thus, referring to the drawing, equation (5) will be explained in more detail.

First, the pattern height T of the image forming layer 401 by which a desired processing depth of a process object substrate 402 can be processed, is determined on the basis of a process condition such as etching durability, for example. In order to make a pattern of this height T, it is necessary that a pattern after development is produced at the field contour line portion outside the field contour line 800, depicted by a thick line in Figure 11.

The electric field distribution below the light blocking film 101 is well approximated by a concentric-circle model, as described hereinbefore. It is seen from Figure 11 that the extension from the edge portion of the light blocking film 101 is approximately even both in regard to the film thickness direction (downward

direction as viewed in Figure 11) and in a direction parallel to the mask surface (horizontal direction as viewed in Figure 11). Therefore, if a pattern after development is produced at the electric field contour line 800 or any electric field contour line outside the line 800, it assures a result that a developed pattern having an extension not less than a distance T, from the edge portion of the light blocking film 101, even in the direction parallel to the mask surface, is produced.

The extension phenomenon from the edge portion of the light blocking film 101 similarly occurs at the opposite side edge of the light blocking film 101.

Thus, the minimum opening interval Kmin of the near-field exposure mask, effective to produce a pattern having a pattern width W just underneath the light blocking film 101, can be set as defined in equation (5), by using the pattern width W and height T.

The value by which the opening interval K becomes equal to Kmin is the value by which the process margin becomes equal to zero. The process margin "zero" means that the margin for the process condition such as exposure developing condition for the pattern formation or the process

after the pattern formation, such as etching or vapor deposition, is zero. With such "zero" margin, actually it is very difficult to perform the pattern formation and subsequent processes for the process object substrate.

Therefore, while taking into account the process margin, the value of the opening interval K should desirably be made not less than Kmin, as given by equation (6) below:

$$K = W+2T(1+\alpha) \qquad \ldots(6)$$

wherein α is the process margin. More specifically, it may be an increment of film thickness affording a margin to the etching durability to the etching of the substrate or a background resist, an increment of film thickness of vapor deposition in the lift-off, a component of overall film thickness dissolution during the development of image forming layer, or a component of dissolution in a direction parallel to the substrate surface during the development of the image forming layer, for example.

While the valueα varies largely with the process, in many cases it takes a value of $0<\alpha\leq 4$. If equation (6) takes a negative value in dependence upon the value of α, a buffer layer may be provided between the image forming layer and the process object substrate as described

hereinbefore, to reduce the values of α and T of the effective image forming layer, such that the opening interval K having an effective and positive value can be set.

A near-field exposure mask having an opening interval K, having been designed in the manner described above, is manufactured, and near-field exposure and development are carried out by use of the mask, by which an isolated fine pattern can be produced.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.